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HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

SOME OBSERVATIONS ON COAL-MINE FANS AND COAL-MINE VENTILATION

BY

D. HARRINGTON AND E. H. DENNY

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SOME OBSERVATIONS ON COAL-MINE FANS AND COAL-MINE VENTILATION 1/

By D. Harrington2/ and E. H. Denny3/

INTRODUCTION

For several years, or from about 1932 to 1935, inclusive, the coal industry of the United States had an excellent record as to coal-mine explosions. In 1937 and in 1938 to date there has been a definite increase in the number of explosions attended by considerable loss of life and property damage. In most of these explosions one important underlying and contributing cause has been lack of sufficient (or at least efficient) ventilation to properly dilute and remove explosive gas from the mine. This increase in explosions indicates that the lesson taught through bitter experience, many times in the not far-distant past, of the need for good ventilation is frequently being overlooked, partly because the relatively good experience of the industry in the past several years has made many mining people forgetful. Moreover mining practices are rapidly changing, and in some instances the changes are being made with little if any regard for safety. It appears, therefore, that a review of some ventilation principles and practices should be of value in preventing further disasters; this paper has been prepared with that object in mind.

In coal mining the need for thorough ventilation of all underground working places is recognized by both mining practice and law; such ventilation is generally obtained by the use of fans that circulate a quantity of air much in excess of the quantity of coal produced, by weight as well as by volume. For example, in a relatively small mine producing 1,000 tons of coal per day and circulating 100,000 cubic feet of air, which is by no means abnormal, 2,000,000 pounds of coal and approximately 10,900,000 pounds of air would be moved out of the mine every 24 hours. Because of the need for adequate dilution and removal of methane issuing or likely to issue from mine strata and for removal of the carbon dioxide formed by coal and timber oxidation up-to-date coal mines usually provide an air volume which if adequately coursed not only removes these gases but also the gaseous products of the detonation of explosives (which may include carbon monoxide, hydrogen sulphide, nitrogen oxides, carbon dioxide, and nitrogen) and the carbon

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dioxide exhaled from the lungs of men and animals. Adequate coursing of air supplies the worker with air of normal (approximately 20.9 percent oxygen) quality, which moves with enough velocity and is adequate in volume to evaporate perspiration and usually is maintained at a temperature such as will promote the worker's efficiency.

VENTILATION LAWS AND REGULATIONS

The laws of virtually all coal-mining States recognize good ventilation as a main safety requirement; the provisions of the laws on ventilation largely agree or at least are similar in many respects. Several mining States recently have amended their laws to allow for new knowledge in safety practice and new mining methods and equipment. The operating regulations of the Federal Government covering coal extraction on leased lands and the Pennsylvania and Colorado coal-mining codes are among the codes that have been amended recently. Examination of some of the provisions relating to ventilation gives an idea of the current trend in ventilation practice. It should be noted that some of the changes made in laws and regulations apply only to the new mines opened or newly coming under regulations.

Government Regulations for Leased Lands

The Operating Regulations to Govern Coal-Mining Methods and the Safety and Welfare of Miners on Leased Lands on the Public Domain[4/] provide (changes in regulations apply principally to new leases) that "the main fan of a mine shall be situated on the surface at an offset distance of not less than 25 feet from the projection of the nearest side of the opening of the mine to the fan wheel, and shall be protected with explosion-relief doors having the full area of the air shaft or airway and in direct line therewith." They also require a fan with an arrangement for quickly reversing the air current, operation of the fan while men are in the mine and withdrawal of men in event of fan failure, operation of the fan for specified periods before men other than mine examiners enter the mine, continuous ventilation pressure recorder, automatic signal to give warning of fan slowing down or stopping, and fan house of incombustible material.

Electrically driven fans at gassy mines must have permissible motors and be provided with auxiliary power connection. Some of these provisions do not apply to small mines or may be waived by written consent of the district mining supervisor.

"Booster" and auxiliary fans may be used underground under these Leasing Regulations only with the written permission of the district mining supervisor under specified conditions. With a "booster" fan these conditions include protection against fire, an automatic starting and timing device to prevent a fan from starting after it has been stopped long enough to permit an accumulation of gas, and a recording device to show continuity of fan operation. Also "a booster fan shall not be operated where more than 10 percent of the air is recirculated by the fan."

4/ Revised regulations printed in Federal Register, Vol. 3, Feb. 25, 1938. p. 515.

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The Leasing Regulations provide that an auxiliary fan must be "in an intaking air current and at least 16 feet outby the last open crosscut or entrance to the place ventilated" and the motor and switch be permissible. Also in gassy mines a "gas inspector or fireboss shall be in attendance in the vicinity of the fan at all times while the fan is running and shall make hourly inspections" of the fan and its surrounding atmosphere. "Auxiliary fans shall not be used for the purpose of moving bodies of gas", and the ventilating current must be such as "to keep the working places clear or gas." This provision apparently implies that if at any time, even when an auxiliary fan is not operating, gas is detected in a place by a flame safety lamp the auxiliary fan cannot be used to ventilate the place; recourse must be had to the driving of crosscuts or use of line brattice or both to ventilate the place.

The Leasing Regulations state that the term "permissible" applies to "electric machinery - officially listed as 'permissible' by the Bureau of Mines and approved as having met its requirements for the respective specified uses." To date the Bureau of Mines has listed no fans or motors as permissible and tests and approves no motors separately as permissible. Its policy is to test and approve only complete units of machinery; it would seem that a change in the Bureau of Mines test policy or a revision of its definition of "permissible" would be necessary before any electrically operated auxiliary fan can be used legally in a Federal coal lease and before an electrically operated surface fan can be used at any gassy coal mine opened hereafter. Possibly this regulations and that referred to later in the Pennsylvania law will be interpreted to mean an explosion-proof motor identical in construction with those used on permissible equipment.

The Leasing Regulations further stipulate that "the lessee shall provide a ventilating current of not less than 100 cubic feet of air a minute for each person employed underground on any shift and 500 cubic feet a minute for each mule or horse or such larger amounts as may be required by State laws"; this required quantity is to be measured for each split "at the entry, crosscut, or break-through nearest the face." There are also provisions regarding the quality of air, some requiring an oxygen content of 19.5 percent or more and a methane content of not more than 2 percent at the working face and not more than 0.75 percent in the general body of air. Not more than 75 men can be employed on any air split, except by written permission of the district mining supervisor.

Pennsylvania

The bituminous mining laws of Pennsylvania (1937) (sec. 6, p. 67) state that no main or principal ventilating fan shall be placed inside any mine. Continuous operation of "every ventilating fan at gaseous mines" is required "unless operations are definitely suspended." "Booster and/or blower fans" are allowed in gassy mines to ventilate workings having no connection with the air circuit if they are equipped with a Government-approved, flameproof electric motor and if the location of such fans is approved by the district inspector. If an electrically driven auxiliary fan is used in

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a gassy mine its motor must be placed in the intake airway. Apparently the term "auxiliary fan" in the Pennsylvania law means any fan used underground to supplement main ventilation.

In gassy mines a minimum quantity of 200 cubic feet of air per man per minute is required and "the ventilation shall be conducted through the main entries, cross entries, and to the working faces of all working places in the mine in sufficient quantities to dilute, carry off, and render harmless the smoke and the noxious and dangerous gases generated therein, to such an extent that all working places and traveling roads shall be in a safe and healthy condition for the persons working and traveling therein"; 150 cubic feet per man per minute is required in a nongassy mine.

In addition to the requirement that air be measured at the last cut-through in the last room and in the entry beyond the last room turned, provision is made for determining the methane content of the air in returns by analyses or by sensitive methane detector. An overcast or undercast is required on the return from each split where 70 to 90 men are employed, and not more than 90 persons may work in the same continuous air current. "Openings, except entries, may be driven 150 feet without cut-throughs," provided that such opening or working place be examined by a mine official at least three times a day during the working shift or shifts, that not more than three such working places are on any one split, and that, in gassy mines, such places are adequately rock-dusted.

Colorado

The coal-mining laws of Colorado (1937) provide that surface fans be offset a distance of not less than 20 feet from the aircourse, that they be so constructed that the air current can be reversed immediately, that in all operating mines they be kept running continuously unless by permission of the chief inspector, and that a water gage be used where possible. "All fans at gassy mines shall be equipped with an auxiliary power plant or an automatic signal and automatic power release", this signal to give warning of the fan slowing down or stopping.

Underground fans and small power and hand blowers may be used if written permission of the chief inspector is obtained. Ventilation of a mine solely by an underground fan without a surface-fan installation is prohibited. Small blowers permitted for face ventilation must be installed on the intake side of the last crosscut in a manner that will not permit recirculation of air; not less than 100 cubic feet of air per minute must pass through the last entry crosscut for each man employed in the district. If a blower fan is used the distance to which a single place may be driven without crosscuts is limited by a provision of "adequate ventilation at the face." Provisions relating to air splits and air quantity per man are similar to the laws and regulations previously discussed.

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Wyoming

The Wyoming coal-mining law (1937) (pars. 23-110, inclusive) on ventilation provides for 150 or more cubic feet of air per minute per man in the mine, such air to be circulated around headings and working places to adequately dilute, carry off, and render harmless gases generated in the mine; 50 men or less are allowed on a single split. No specific requirement is made for fan installation. Main fans at operating gassy mines must be operated continuously or the men safeguarded if the fans are shut down for repairs or other cause. A recording instrument for measuring ventilation pressure is required on all main fans and the foreman must examine the fan-pressure record and satisfy himself that the fan has been operating continuously for at least 6 hours before the working force enters the mine. Development places or entries may be driven 300 feet ahead of the last crosscut, but in that event proper brattice or other means must be used to carry air to the working face. If an entry or passageway is ventilated by a blower fan, the fan "shall be located at least 25 feet distant from the returning air, and said fan shall be so located that the returning air shall not reenter the fan, and provided, that the outlet end of tubing used in connection with such blower fan shall not be more than 40 feet from the working face."

New Mexico

The New Mexico mining law permits the use underground of electrically driven auxiliary fans or blowers only in a nongassy mine in an emergency and only upon issuance of a written permit by the State mine inspector. Crosscuts must not be driven more than 100 feet apart unless greater distance is authorized by the mine inspector.

Other States

The provisions of other State coal-mining laws are similar to those detailed above. The laws and recent changes thereto constitute a recognition of the need for circulating an adequate volume of fresh air in all parts of a mine. They also attempt to provide for ventilation of the face workings advancing now much more rapidly by mechanical loading systems than under old hand-loading systems. Such provisions make an effort to guard against new hazards to life from the added ventilating equipment. Analysis of the many requirements regarding ventilation discloses definite reasons for each requirement based upon the coal industry's thought and experience, and oftentimes this experience has consisted in a large loss of life and property by fires or explosions or both.

EXPLANATION OF VENTILATION REQUIREMENTS

Mechanical Ventilation

Mechanically induced ventilation with air from outside the mine is required because it is known that irrespirable gases are likely to be encountered in mining operations. This knowledge is reinforced by the fact

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that scores of persons have been asphyxiated in mines on entering openings not ventilated from the surface; some of these deaths have been caused even in sight of open air. In a recent fire in an abandoned drift mine the recovery of the body of a man required the laying of a power line for a mile, the installation of a small fan, and the use of line brattice and oxygen breathing apparatus, and ultimately resulted in the loss of two additional lives. For years both safety and efficiency have required that main fans be installed on the surface to supply ventilation for coal mines because surface main fans have been found effective, they are readily accessible in event of disastor in the mine, and fan failure can be quickly detected and breakage repaired in safe and well-lighted surroundings; it is therefore imperative that the coal-mine operator who protects his mine and his men place an adequate fan in a fireproof housing on the surface.

Incombustible Materials for Fan and Housing

Requirements that fan and housing and connection to the mine be of incombustible material or lining are based on the experience that if a fan motor should overheat and set fire to the housing or if the housing or connections should be fired from some other source, while the fan is operated blowing, smoke and flames immediately will be directed into the mine, timber and coal will fire quickly, and men probably will be overcome and killed in all parts of the mine. If a fire should start in the vicinity of a fan that is operated exhausting the consequences are likely to be less serious. However, fire started at or near the fan may fall into the mine, or its gases may be drawn into the mine by natural currents when the fan connection to the mine is burned out.

Warning Devices

Requirements that devices be used, particularly in gassy mines, to warn of fan stoppage have resulted from the fact that the main ventilation may be shut off entirely without the knowledge of mine officials in remote parts of the mine and hazardous conditions may arise from gas accumulations where igniting agencies, such as electrical equipment, open lights, etc., are in use. In one mine - by no means the only one of the sort - shots were fired, and haulage locomotives operated after the fan stopped without the knowledge of mine officials, and a general mine explosion resulted. The provisions regarding explosion doors and offsetting of fan are the result of fan damage or complete wreckage by a mine explosion when the fan was in direct line with or in a mine opening or when explosion doors were inadequate, fastened down, or were lacking. Placing a main coal-mine fan underground has so many unsafe features that it should not be allowed.

Provision for Reversing Air Current

The regulations requiring a means for reversing promptly and effectively the direction of air currents recognize the dangers that sometimes arise in normal direction of air flow when smoke or afterdamp is directed upon persons attempting to escape from a mine or when the usual entrance to the

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mine and main haulageways is on the return air, as in many mines, making safe and ready access to or from the mine difficult if not absolutely impossible. In one mine, where the fan was operated blowing, the emergency cage at the air shaft would not function after an explosion. The provision that reversal be made only by authority of a competent person recognizes that often the reversing of a fan after an explosion or a fire may trap men who are attempting to escape when reversal causes irrespirable gases to be directed into a passageway which the underground workers know is normally an intake airway and are using as an exit for escape.

Booster Fans

Underground fans of the "booster" type have been used in relatively isolated places for many years, usually to ventilate some part of a mine distant from the surface fan and mine openings. Commonly State laws subject any such installation to the State department's permission and to other restrictions. The evident suspicion with which State regulations regard booster-fan installations is justified by numerous disasters due to their use or misuse, in one of which 20 lives were lost, a fire was fought for many days, and the mine was sealed for several months because the motor of a booster fan overheated and the coal rib was fired. Innumerable fires and explosions in coal mines originating from underground-fan installations (main, booster, and auxiliary) amply justify the statement that they constitute a continuous hazard and their use should be allowed rarely if at all.

The Mine Safety Board of the Bureau of Mines defines5/ a booster fan as an underground-fan

> Installation through which is passed the whole particular circuit of air to increase its pressure (negative or positive) so as to overcome resistance, with the object of increasing the volume, and/or forcing the air in adequate amount through distant workings.

The Mine Safety Board concludes:

> The use of a "booster fan" is rarely justified. In most installations investigated there was recirculation of the air, and where this happens if methane is given off in the circuit there is a corresponding increase in gas content in the air circulated. Explosions have resulted therefrom. The best way, which is ordinarily sufficient, is to improve airways and/or to install a more powerful surface fan to obtain adequate pressure and volume of circuits of air throughout the mine. A booster-fan installation should be contemplated for ventilating a distant extension of a mine only where it is not practicable

5/ Mine Safety Board, Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of October 1, 1936: Inf. Circ. 6946, Decision 4, Bureau of Mines, 1937, p. 11.

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to put down a new shaft and when, after all has been done that is possible to improve the airways, the air pressure required would be so high (exceeding 5 inches water gage) as to prevent proper operation of the underground ventilating doors.

Auxiliary Fans

Small, electrically operated auxiliary fans or blowers have been used to some extent in coal mines for a number of years; they are now coming into far too general use in several States, if due consideration is given the health and safety of workers. The Mine Safety Board of the Bureau of Mines states6/

> Auxiliary fans or blowers by contrast with booster fans are temporary installations, usually electrically driven, commonly intermittently operated and taking part of the air current, and used to carry air usually through tubing to dead ends and places through which air is not being regularly and continuously coursed.

They have been used for many years to advantage in tunnels and metal mines with canvas or metal tubing to remove gases from explosives and to furnish moving air currents in stopes, winzes, and ends of drifts. In such use they generally increase the comfort and safety of the miners and also materially increase their efficiency. A small unit furnishes several hundred cubic feet of moving air per minute as compared with the former method of 75 to 100 cubic feet of air per minute from a compressed-air pipe or drill. The quality of the air delivered depends upon the source; if the fan is on a level with little or no circulation of air because of lack of connections to other levels, the chief advantage of the blower may be dilution rather than removal of gases, and the comfort afforded may be merely that due to better evaporation of perspiration by moving air.

In coal mines an early use of auxiliary fans and tubing was in the driving of single entries or tunnels through rock or rock faults where cost considerations seemed to justify only one passageway. Ventilation stoppings almost invariably leak, and there appeared to be a logical use for auxiliary fans as they permitted the driving of crosscuts at longer intervals with less loss of air and more thorough ventilation of remote faces; moreover the driving of fewer crosscuts speeded up development, particularly in mechanized mining. Also it was evident that auxiliary fans and tubing could be used to furnish ventilation for long face systems of mining. At first auxiliary fans were advocated only for nongassy mines because of the danger of ignition of gas and general explosion hazards involved in intermittent ventilation of a place and the use of electrical equipment; however, owing to competition and other conditions, chiefly in connection with mechanized

6/ Mine Safety Board, Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of October 1, 1936: Inf. Circ. 6946, Decision 4, Bureau of Mines, 1937.

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loading systems, they are being installed in gassy mines regardless of the hazards involved. Occasional gas accumulations have been and are being moved with them, supplemented in rare instances by use of a line brattice.

Hazards in the Use of Auxiliary Fans Underground

The prediction of hazards from ignition of gas and fires resulting directly or indirectly from the use or misuse of auxiliary fans has been borne out by numerous explosions. In recent years the Bureau has received reports of several gas ignitions resulting directly from the misuse of auxiliary or blower fans. In one instance a man was seriously burned at the face of an entry for which canvas tubing and an auxiliary fan were supposed to provide ventilation. Gas was ignited by the victim apparently while hammering a bolt to remove a conveyor pan; irrespective of the cause of the ignition, unquestionably the gas accumulated through inefficiency in the ventilation supplied by the fan-tubing combination.

In another mine rated as nongassy a blower fan recirculated the air to such an extent that a considerable section was filled with an explosive mixture of methane and air. One miner lighted a cigarette and an explosion followed, killing 14 men. In another mine a blower fan used to ventilate the face of an entry was not in operation. A miner proceeded toward the face with a carbide lamp and was seriously burned.

A blower fan and a vent box were used to ventilate a single entry driven 180 feet without crosscuts. The fireboss, who was killed in the explosion, presumably started the fan, as was his practice, before the shift entered. A fall had occurred in the back entry, and as a result the air was recirculated. When the boss discovered that the air was not circulating properly he pulled the fan switch, and an arc resulted which ignited the gas. A well-formulated State mine inspector's report describes a gas ignition from an auxiliary-fan oil switch that caused the death of four men; again, the ignition started at the fan switch, and again gas was ignited when the switch was opened. The gas had backed up around the fan which was slightly on the intake side of the last crosscut. Two auxiliary fans were used here, one to ventilate the entry face and the other the aircourse face; the fan used to ventilate the aircourse face was set on the return from the other fan. It apparently had been the practice to blow out the gas from the entry face first into the return and then start the fan which was in the return to blow out the aircourse face. Evidently the air from the fan tubing did not remove the gas quickly enough so the men fanned it with their coats. These practices may have had no bearing upon the explosion, but they illustrate the various short-cuts and dangerous practices attending the use of these fans.

The Mine Safety Board of the Bureau of Mines does not recommend the use of electrically operated auxiliary fans or blowers in coal mines. The Bureau recommendation follows:7/

7/ Mine Safety Board, Recommendations of the United States Bureau of Mines on Certain Questions of Safety as of October 1, 1936. Inf. Circ. 6946, Decision 4, Bureau of Mines, 1937, p. 10.

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> In the interest of safety, the Bureau of Mines recommends that auxiliary fans or blowers should not be used in coal mines as a substitution for methods of regular and continuous coursing of the air to every face of the mine.

The discussion of this statement indicates that if these fans are used they should have motors of the explosion-proof type and should employ armored power conductors; special attention should be given thorough insulation of the wiring, and the vicinity of the fan installation should be fireproof, or, at least, the installation should be well removed from coal ribs and other combustible material to prevent the possibility of a mine fire from electrical break-down or overheating of bearings. If used in a coal mine an auxiliary fan always should be installed on the fresh-air side of the place to be ventilated, and the fan inlet should be not less than 8 feet from the nearer rib of the place ventilated or of the last cut-through, as the case may be. When so placed the fan should not take more than 40 percent of the air current in which it is placed. Line brattices in gassy mines should be kept in place where practicable as in mines having no underground auxiliary fan because such brattices may keep the places clear of gas on off-shift periods when the auxiliary fan is not operating. The special requirements of one State mining department (Alabama, 1938) governing use of auxiliary fans in a gassy coal mine stipulate continuous 24-hour operation of the fan, maintenance of the inby end of fan tubing within 20 feet of the face, rock dusting of advancing work in passages adjacent thereto, examination with flame safety lamp immediately before machinery is started, removal of any gas found only in the presence of the mine foreman or other certificated official, and the stopping of electric machines on the return and removal of all men from the return if gas is discovered.

A main difficulty in using auxiliary fans safely is that they may readily be moved in a few moments from a relatively safe position to one that is definitely unsafe. In the event of shortage of tubing the fan may be moved forward, and even if a supply of tubing is available the fan may be moved forward rather than install additional tubing. The argument might be advanced that the fan after all is being used in places where nonpermissible cutting machines and drills and open types of other electrical machinery and wiring are used and have been used for a long time with few if any difficulties. However, the auxiliary fan not only adds one more piece of unsafe electrical equipment to that already being used, but its presence and operation make dangerous the use of all other equipment because its intermittent operation permits the possibility (in fact, the very strong probability) of the accumulation of explosive gas almost daily. When a blower or auxiliary fan is used explosive gas may accumulate where it would not likely accumulate under the older systems of ventilation; thence it is readily ignited by any one of several sources in present-day coal-mining procedure. Continuous operation of auxiliary fans 24 hours daily would largely obviate the danger but, since in most instances the fans would not be under even intermittent supervision, this would increase the hazard of their being installed so an overheated motor could set fire to the coal, to adjacent timber, or to both. Moreover, auxiliary fans have not proved

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efficient in removing large quantities of standing gas or even in preventing gas from accumulating, as might be expected considering the relatively small discharge outlet for air as compared with the usual methods of regular and continuous coursing of air. An entire face may be swept with air by means of a line brattice, while the canvas tube merely sends a stream or jet of air through a very limited cross-sectional area. The situation is similar to a case in which a man was asphyxiated with oxygen-deficient air and an attempt made to reach the body by the use of compressed-air hose. The hose was so ineffective in stirring up and moving the asphyxiating gases that several hours of its use were required to clear the place so the body could be reached, although only a few feet away.

The use of auxiliary fans undoubtedly will increase unless it is discouraged by several major explosions; hence it would seem that in each State where their use is permitted rigid rules should be enforced with respect to their installation and use; every installation should have prior approval by a State mine inspector, and a definite understanding should be reached that any mine official or employee departing from the fixed rules or regulations would be subject to summary discipline, discharge, or even fine and imprisonment. In addition, frequent reinspections of such installations by company and State officials would insure that the State regulations were followed; otherwise, a harvest of death is likely to result from the rapidly expanding use of these dangerous coal-mine ventilation makeshifts.

DANGERS OF USE OF MAIN FANS UNDERGROUND

Recently some persons have advocated the use of underground fans for main as well as booster and auxiliary ventilation of coal mines supplemented by a surface fan as an emergency stand-by; this is a decidedly dangerous proposal and should be considered so in any coal mine even though justified under some conditions in metal mines. Several large metal mines with shaft openings rely solely on an underground fan or fans for ventilation. Often the installation of the fan underground is due to the fact that rough surface topography makes the surface installation of the main fan almost inaccessible during periods in the winter; a metal mine may have several outlets for air but no one of them capable of carrying an adequate volume of air. Additional reasons for considering the use of a main fan underground might be the desire to use all openings for hoisting or to avoid or reduce shaft-partition leakage where one compartment of a shaft is employed as a man and material hoist and the other for air with the partition in a bad state of repair. Also the use of several underground fans might be desired for most or all of the principal splits perhaps to avoid the use of or limit the number of regulators and reduce maintenance of air courses. These as well as other valid and readily defended reasons justify the installation of main and other fans underground in metal mines under some conditions.

Some persons advocate that in main-fan installations underground in gassy mines the fan motor should be the explosion-proof type and should be

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placed in intake air or on a separate small split whose opening is large enough to allow the fan drive to operate. Also, fireproof surroundings and proper wiring are advocated to minimize the fire hazard. Under some conditions such installations may be efficient and afford some degree of safety. The following questions or considerations arise as to the probable safety of underground installations of main fans applicable to both gassy and nongassy mines, assuming that the main fan would be located underground at a point near a shaft:

1. Will the stand-by surface fan designed to be used in the event of a break-down or partial or total destruction of underground fan by fire or explosion always be ready to operate in such emergency? Will it not require increased and continued vigilance by State and company officials to assure that this fan is always in operating condition?

2. If the fan is maintained in operating condition, will it necessarily provide adequate ventilation for mine extensions 3 or 4 years after the underground fan has been installed, or might it not be necessary in case of a serious explosion or fire at or near the fan to replace the entire underground fan before ventilation could be restored in some, possibly most, of the workings?

3. Assuming that the surface fan is kept in good operating condition, would it necessarily furnish adequate ventilation through the underground-fan installation if the underground fan should break down or be wrecked by an explosion or fire, or should a special bypass be constructed and maintained for such emergency?

4. If the underground fan is installed because of difficulties with shaft-partition leakage would there not be virtually as much short-circuiting of the air in a partitioned shaft whether the fan were on the surface or underground, except that such "shorting" would mean return of return air to fan, in other words, recirculation of gas-laden air with some building up of gas content and consequent tendency to increase gas content of air throughout the mine? Would not the situation be analogous to a large pipe with holes in it - the question arises as to whether a fan at the outer end of the pipe, or the middle of the pipe, or the inner end of the pipe would circulate the most air, an academic one, the repair of the holes in the pipe being the best practical answer?

5. If the underground fan is installed to permit the entire shaft to be used as intake or return and at the same time for hoisting would not the advantage of additional shaft area be outweighed by probable leakage and recirculation of air resulting from the necessary air locks on haulageway?

6. Experience in some metal mines with main underground fans indicates that a large percentage of air is nearly always recirculated; could not recirculation be avoided in coal mines by exercising care in installing the fan and in operating procedures at or near the fan?

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7. The stopping or slowing down of a mine fan either on the surface or underground should be made manifest by a proper signal system. If the surface fan is near other mine buildings there is some additional safeguard in the fact that an employee outside will become accustomed to the slight noise of the fan and quickly recognize the absence of this noise; moreover any unusual noise or other condition such as smoke coming from the motor of the fan may be quickly detected. Would the position of the underground fan always be such that fan failure or an overheated motor would be quickly caught by other than an automatic signal system or might the fan be so located that failures could readily occur without the cager or bottom landing men or other underground employees noting them?

8. If many of these fans are installed in mines (some of which certainly will be installed without adequate fire protection, proper location of motor, etc., as definitely has been the experience with booster fans) will not the general use of main fans underground be likely in the aggregate to add definitely to the occurrence of mine explosions and fires?

RECOMMENDATIONS

The following recommendations are made in addition to those previously given, some of which, however, are restated or amplified:

1. Every coal mine, large or small, should be mechanically ventilated by a fan on the surface. The fan should be of sufficient capacity to give the workings an ample supply of air. It should be in fireproof housing and so arranged that the direction of air currents can be reversed with essentially no delay; the arrangement for reversing should be tested at least once a year. The fan should not be in front of the mine opening but should be offset so it will not be damaged by an explosion. Preferably it should have two sources of power. At very gassy mines (those in which the return air from any split runs as high as 0.5 percent methane) it is desirable to have two fan units, one driven by one source of power and the other by a different source, one of these units being a "stand-by." The power line to the fan should be independent of the power lines that enter the mine. There should preferably be some automatic method of cutting off electric power to the mine when the fan slows down or stops. The fan should have a recording water gage and should be either constantly attended or have some automatic alarm to indicate any interruption or interference with the normal flow of air. In general, the water gage should be less than 5 inches.

2. Every mine should be so ventilated that no face or other unsealed place should contain at any time over 1 percent methane, or approximately 1 percent carbon dioxide, or less than 19 percent oxygen; no circulating current in a split return or main return should contain over 0.5 percent methane or 0.5 percent carbon dioxide. Air with a carbon dioxide content of approximately 1 percent or oxygen content of 19 percent, very probably would not be harmful physiologically yet would indicate sluggish or defective circulation of air.

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3. Velocity of the air current in any air course should not exceed 1,500 linear feet per minute; preferably the velocity should be held below 1,000 feet per minute.

4. No main aircourse - whether shaft, slope, or drift - should act as both intake and return; and no one underground opening longer than 200 feet should act as both intake and return if more than five persons depend upon that opening for ventilation or exit. The driving of single entries more than 200 feet long should not be allowed in any coal mine; under unusual circumstances, however, the appropriate State authority might allow the driving of a single underground passageway larger than 200 feet if adequate precautions are taken.

5. The main return should not be on the main haulage, especially if the main haulage road must be used to handle men.

6. Trolley locomotives or other types of open electrical haulage or other electrical equipment should not be allowed in return air. Nor should trolley locomotives run past open rooms or pillar workings that give off methane or past sealed areas known to contain large quantities of explosive gas; nor should they operate any nearer than 500 feet to any advancing face known to give off methane.

7. Crosscuts between entries, other than the last crosscut nearest the face, should be closed by tight fireproof or fire-resistant stoppings; under no circumstances should dirt, gob, wood, or brattice cloth be used for this purpose unless effectively backed by concrete, plaster, or other material that will render the stoppings strong, tight, and fire-resistant.

8. Mines should be divided into sections or panels in such manner that each section can be ventilated by a separate split; in case of fire or explosion the return from each section will go to the main return without vitiating the atmosphere of adjacent sections. Moreover, the entrance to every opening to each such section should have a fire-resistant door, so that in case of fire within a section the closing of a few doors will isolate the region and confine the gases within. Preferably coal-mine ventilation should be ascensional, the air going from a lower to a higher elevation as it courses through the mine workings. This is especially desirable in mines on a relatively steep pitch.

9. Aircourses should be large enough to permit an adequate flow of air to keep the methane as well as carbon dioxide content below 0.5 percent and yet not necessitate velocities in excess of 1,500 feet per minute or a water gage of more than 5 inches.

10. Main aircourses should at all times be kept clear of falls; abrupt turns (either vertical, as to overcast walls, or horizontal, as in mine intersections at angles of 90° or more) should be avoided; water should not be permitted to partly close the passageways; and walls, floor, and roof should be kept as smooth as possible and as free as feasible of obstructions,

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such as center posts, cribs, gob walls, etc., which deflect the currents or cause eddying. In many mines it would pay to maintain track in both intake and return air courses to aid in keeping the air courses cleaned.

11. When mine workings reach distances of a mile or more from the fan, it is good policy, with respect to cost, efficiency, and safety, to maintain air openings to the surface that are fairly close to working regions. These openings - whether shafts, slopes, or drifts - relieve fan pressure, bring fresh air to the faces where it is needed, and serve as escapeways or exits at time of disaster. Rigid and efficient ventilation surveys should be made from time to time to detect conditions that decrease air flow to the places that require it.

12. Cages, skips, cars or trips should not be left in aircourses when not in use or overnight in such manner as to block or partly block air flow. Such blocking of air currents is common in mines, yet rarely is there any real necessity for it.

13. Coal mines should be planned so that the minimum number of doors need be used at ordinary working periods - especially doors on haulage roads. The proper function of mine doors is for use in emergencies. Where doors are necessary, both door and frame should be tight at all times and so constructed that the door will close automatically and remain closed unless considerable pressure is exerted against it. Doors that open easily are a distinct menace to safety in mines yet should be so constructed that they can be opened readily by one man's strength. Preferably they should be in pairs with an air lock between, so that when one door is open the other will be closed; if there is not enough room for two doors with an intervening air lock, there should be a fire-resistant brattice curtain in place of the second door to aid in holding the air in its proper course while the door is open. No latch should be allowed on the rib to hold any ventilation door open, and no person should block open an important door that is intended to be kept closed, as many explosions have occurred both recently and in the past as a result of ignition of explosive gas that had accumulated while doors were blocked open by drivers, motormen, or others.

14. All doors, doorframes, overcasts, regulator stoppings, and other underground ventilating structures or equipment should be fireproof or at least fire-resistant. Where brattice cloth or canvas are used they should be treated to resist fire. Timber covered with gunite or with roofing or other sheet iron resists fire fairly well, but overcasts, doorframes, and regulators, as well as stoppings between main or other important aircourses, should be of concrete or similar construction.

15. All crosscuts in rooms, except the last crosscut nearest the face, should be closed by tight, fire-resistant brattice or stopping; such stoppings are neglected in many mines where methane is not particularly prevalent. Where methane is found line brattices should be used to a point within 15 feet of the face to bring circulating air to the face; where it

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is fairly likely to be found the brattice man should leave 15 to 20 feet of brattice cloth at the end of the line brattice so that the face worker can use it to keep air at the face as it advances.

16. All parts of mines that are worked out or are temporarily or permanently abandoned should be sealed with strong, tight, fireproof stoppings, unless such places must be held open for travel, ventilation, or other useful purpose of operation or safety; the stoppings should be examined weekly or, preferably, daily and should be kept in good repair. Pipes with valves should be placed in sufficient seals to enable testing of air in sealed areas; the tests should be made by dependable persons who realize the hazards that may be encountered with gas.

17. Stables, transformers, or other electrical stations, and similar places where men are likely to congregate or inflammable material is likely to be in use should preferably be of fireproof or fire-resistant material on a small separate air split or should be so arranged as to be readily isolated by doors or similar method in event of fire.

18. It is decidedly poor practice to ventilate one mine through another or even to connect two mines, particularly if one or both give off methane. There is grave doubt as to the advisability of allowing as many as 500 men underground at any time in any one mine. Where large numbers of men are employed underground there should be approximately one exit to the surface for every 150 or 200 men underground; these should always be safe for travel, and readily readable exit signs should direct workers to and through these escapeways.

19. Bare electric power wires or open types of electric motors or switches or other electrical equipment that arcs or sparks should not be allowed in return air in which any methane is present or in regions where there is much fine, dry inflammable coal dust.

20. Ventilation in mines employing more than 100 men on any one shift should be under the direct supervision of one person who, preferably, should not be the mine foreman, because his many other duties do not permit him to give ventilation the time and attention it deserves and needs.

21. Every mine should be examined before the shift by competent firebosses; they should be able to do all their work in not more than 3 hours and yet spend at least 5 minutes at every place or face where men work. They should not be required to cover so much territory that they must travel faster than a fairly brisk walk and should not examine any working face more than 3 hours before the workers enter the mine. Their examination should include all hazardous conditions, including those of the roof, rather than be confined to gas conditions alone.

22. Open lights or smoking should not be allowed in any coal mine; most certainly no fireboss or other mine official should ever carry into a coal mine a match, open light, or smoking materials of any description

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either on his preshift examination or to his work in the mine during the working shift or at any other time. A boss should be provided with a permissible magnetically locked flame safety lamp and some form of up-to-date permissible electric lamp. Several types of methane indicators or detectors now on the market can readily detect methane in smaller percentages than the flame safety lamp and with greater safety and accuracy; every mine should be equipped with one or more of these devices.

23. Flame safety lamps should not be entrusted to any person who has not received from the State a certificate of competency as to his knowledge of the flame safety lamp and his ability to use it with safety and efficiency. Certainly no single-gauze or other relatively unsafe type of flame safety lamp should be allowed in any coal mine. The flame safety lamp at its best is none too safe; hence only permissible flame safety lamps should be used.

24. No person should be allowed to use a flame safety lamp in a mine unless he has received a certificate from a competent eye specialist stating that his eyesight is normal or that proper glasses have been supplied to correct his vision so there is a reasonable quaranty that the person using the flame safety lamp will be able to see the gas cap should one be present.

25. Mine officials - including shot firers, firebosses, foremen, and superintendents - should have technical or school training in mining and engineering, in addition to mining experience. Mine foremen, firebosses, and shot firers should be required to hold a certificate of competency from the State; it is decidedly desirable that States have some form of certificate of competency for mine superintendents. Certificates should expire at least every 5 years and should not be renewed unless the applicant passes a rigid examination indicating that he is physically able to do his work and has kept himself informed as to up-to-date requirements of the State law, company regulations, and sane practices in mine safety. The applicant particularly should be required to be familiar with the dangers from gas, dust, explosives, haulage equipment, electricity, and falls of coal and roof and to suggest safe and efficient methods of avoiding or overcoming these dangers. He should also be required to have a knowledge of safe procedure at the time of mine fires or explosions and be familiar with such instruments as the anemometer, barometer, psychrometer, flame safety lamp, other methane detectors, Orsat apparatus, etc. These requirements seem drastic, but far too many disasters and accidents are due to the lack of knowledge and the inefficiency of mine officials. The abnormally high accident rate of our coal mines will not be reduced materially until matters relating to safety are given more intelligent supervision.

26. Whenever an open fire or a new fire, the nature and location of which is uncertain, occurs in a mine the working shift should be withdrawn as soon as possible and not permitted to return until the fire has been extinguished or sealed. During sealing operations no men should be allowed in the mine other than those engaged in the sealing work.

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27. Whenever the main fan stops or is "slowed down" all underground workers should be withdrawn; they should not be permitted to return until fan operation has been resumed and all accessible open places have been examined thoroughly and found free of gas.

28. Any mine known to give off methane should be given the usual rigid preshift fireboss examination before workers enter the mine even if work is being done on a so-called idle day.

29. Firebosses should make a signed statement on a report as to mine conditions before the working shift is allowed to enter any coal mine. The written record should state the size of "cap" wherever any explosive gas is found, give an estimate of the number of cubic feet present, and designate with fair accuracy the place where the gas was found. This report and signed statement should be read by the mine foreman and countersigned by him before the men enter the mine. No workers should be allowed to enter any place where an explosive mixture is present.

30. If an accumulation of as much as 100 cubic feet of an explosive mixture of methane and air is found and cannot be removed from the mine before the working shift enters the mine, the place should not be worked nor should any work be done on the return side of the place; moreover the region should be guarded against intruders. Under some circumstances the ignition of as little as 150 cubic feet of an explosive mixture of methane and air can precipitate a widespread explosion in a dusty coal mine.

31. An accumulation of 100 or more cubic feet of an explosive mixture of methane and air should be moved only when all persons are out of the mine, except those actually and actively engaged in moving the gas; and, if possible, all electrical current should be shut out of the mine while the gas is being moved. Use of wafting methods, sprinkling with water spray, or similar means of artificially mixing the methane with surrounding air is dangerous, ineffective, and often disastrous. These bodies of gas accumulations should be moved only by bringing active circulating air currents to the place of occurrence to insure that no more gas will collect at the same place in a short time. No persons should be allowed to move methane or to assist in moving it, except men of more than average intelligence acting under the supervision of the mine foreman, fireboss, or other person or persons holding a certificate of competency by the State.

32. When methane occurs in proportions that are not explosive (less than 5 percent) in air of underground working places more rock dust must be used than the actual amount needed to prevent pure coal dust in pure air from entering into an explosion. For example, if 60 percent of rock dust is needed to prevent entrance and participation of a certain coal dust into an explosion, an additional 8 percent would be required to prevent such participation if 1 percent of methane were present in the air, an additional 16 percent if 2 percent of methane were present, an additional 24 percent if 3 percent of methane were present, etc. This fact indicates the paramount importance of always keeping methane well diluted in all coal mines,

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particularly at the face where both gas and finely divided coal dust would most likely accumulate. It also emphasizes the absolute necessity of diluting methane in mine air as much as possible and the importance of employing watering methods at the face (water on the cutter bar of mining machines, sprinkling of coal pile and coal in loading machines, etc.) to prevent the fine coal dust produced by the various face operations from floating in the air or from settling on adjacent surfaces (floor, walls, roof, timbers, etc.).

CONCLUSION

Ventilation is one of the most important single operations in mining, not only in protecting the health and lives of mine workers but also in promoting efficiency in operation and in lowering costs. Certainly no other single phase of health and safety work affords greater protection to those employed in mines than an efficient ventilation system; on the other hand, lack of ventilation of the proper type is now and always has been the fundamental cause of much ill health and most of the accidents, particularly those of a serious nature, that afflict mine workers.

Methane ignitions have initiated much more than half of the explosions in the coal mines of the United States with resultant loss of many thousands of lives; virtually all of these explosions, as well as the fatal and non-fatal accidents resulting from them, would have been avoided had the ventilation system been as effective as it could and should have been. Relatively few of the most gassy coal mines have had explosion disasters, largely because in these mines the explosive-gas hazard is so obvious that it must be taken into consideration and handled adequately. Mining companies having exceedingly gassy properties are aware of this fact and know what to do to avoid disasters, as is amply proved by the fact that very few disasters have occurred in the very gassy mines of the United States (those producing around 1,000,000 cubic feet of methane per 24 hours). The record shows that the most destructive mine explosions in the coal-mining history of the United States have occurred in the "slightly gassy" or so-called nongassy mines (namely, those producing less than 250,000 cubic feet of explosive gas per 24 hours); these mines usually have main-return air currents carrying less than 0.25 percent methane.

No mine can safely be considered nongassy, as there are scores of mines that have been operated for years without any manifestation of explosive gas and almost overnight (sometimes in a very few minutes) have become definitely gassy. The real answer is that all coal mines, as well as all parts of coal mines, should be considered potentially gassy and should be operated as carefully as if they actually were known to contain explosive gas. Until all mines are so operated "unexpected", "unexplainable", or "unusual" explosion disasters will continue and mine workers will be sacrificed when they enter unexpected gas accumulations. Certainly no coal mine today should use open lights, mixed open and closed lights, open types of electrical equipment that arcs and sparks, black blasting powder, dynamite in any form or for any purpose, internal-combustion engines, or

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allow smoking or the use of nonpermissible flame safety lamps by persons incapable of using them with reasonable safety. Even when ventilation is made as effective as is humanly possible all of these dangerous practices or equipment should be avoided; certainly ventilation should not be neglected to the extent that it is and has been. Coal-mining companies alive to their responsibilities will not adopt well-meant but hazardous short-cuts or any of the numerous nostrums now being proposed in connection with mine-ventilation equipment and methods but rather will adhere to tried and true methods which for years have demonstrated their worth in preventing ill health and accidents even in the most gassy mines of the country.

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